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# Satellite and Radar Forecast Techniques for Short Term Prediction of Storm Motion on the Remote Atmospheric Processing and Display (RAPID) System

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Two forecast techniques were developed based on trend extrapolation of storm boundary (represented by a fixed level contour) attributes. The two techniques differ in the selection of attributes upon which the forecast is based. The first technique performs an extrapolation of spatial characteristics of the system in order to predict position and shape. The second technique treats the storm boundary coordinates as periodic functions represented through Fourier transformation as a series of phase and amplitude coefficients. The magnitude of the coefficients, along with some physical constraints such as area or aspect ratio, are extapolated to produce the forecast. The accuracy of the two techniques is currently under evaluation and results will be presented in a separate report.

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## 1. INTRODUCTION

Remote Atmospheric Processing and Interactive Display (RAPID) is a software package that was developed to produce mesoscale forecasts of precipitation and cloud field phenomena making use of radar and satellite data (Bohne et al., 1988). Radar reflectivity can be interpreted as a measure of precipitation intensity, while satellite infrared data gives a measure of the cloud fields.

The RAPID system provides the meteorologist (the intended end-user) with user-friendly tools with which to display multiple data sources and to process, analyze, and finally forecast the data interactively.

RAPID is a fully independent component of a larger program named the Advanced Meteorological Processing System (AMPS). The objective of AMPS is to develop forecast methods to be used by the Air Force Automated Weather Distribution System (AWDS). AMPS will assist AWDS in the derivation of local phenomena.

The time range of RAPID forecasts is currently 0-0.5 hours. Interest in generating short-term forecasts in real-time has emerged as a consequence of greater computer power at a lower cost. Because of its computationally intensive nature, numerical modelling of local phenomena within the timeliness constants imposed by nowcasting applications is still the province of large computers. In order to achieve the goal of producing nowcasts of mesoscale features on a mini-computer, we developed a methodology for RAPID based on extrapolation of observed trends.

In RAPID, the processing time needed to produce a forecast is reduced by simplifying the data prior to the forecast: both satellite and radar data are smoothed and contoured. Contouring of data produces an abstraction of a scene wherein all neighboring points having the same pixel value are represented by a single entity with a specified shape. This shape is then identified by its boundary or perimeter. This simplification requires significantly less disk space for archiving case studies, and only a relatively small number of computations are necessary to produce the forecast.

The rationale behind short term local forecasts of clouds and precipitation is that communications between satellite and ground station systems are

affected by the intervening meteorological environment. Higher frequency communications systems are particularly vulnerable to clouds and precipitation. Accurate nowcasts of these phenomena offer potential as an operational technique for identifying situations that can disrupt communications (Bohne and Harris, 1985). Timely short term forecasts of clouds and precipitation serve other purposes as well. They can provide assistance to a meteorologist in detecting and characterizing possible atmospheric hazards to aviation so that the information can be passed on quickly to pilots before take off or during flight.

Since those mesoscale phenomena that have a short lifetime and are limited to a local area are not included in the existing numerical model output or in the synoptic report currently available to Air Force pilots, a system like RAPID, able to display the latest data and to produce a quick forecast, becomes critical for operational forecasting.

RAPID is characterized by the following:

- it is capable of displaying, analyzing, and processing data from multiple sources;

- it supports multiple forecast techniques (new forecast techniques can be incorporated into the system);

- the current forecast techniques use mathematical, non-physical based models: the forecasts are the result of extrapolation of contour features. The techniques can, however, be modified to include physical and historical information to improve the accuracy of the forecasts;

- the system provides tools for regression and correlation analysis which can be used to help validate a forecast;

- it is universally applicable: the forecast techniques can be applied to different data sources and the absence of physical information does not preclude its use in different geographical areas;

- it provides an efficient method for archiving case studies; and

- it is a user-friendly and easy to learn system.

## 2. SYSTEM DESCRIPTION

RAPID system hardware consists of color DEC VAX workstations and an Adage image processing computer. All RAPID hardware are networked via an Ethernet link. The DEC components run in a VMS environment operating with workstation software. All software was written in C and Fortran. The software packages used were GKS (for graphics), UIS (for bitmapping of images), SMG (for screen management functions) and IMSL (for statistical analysis).

The RAPID software was developed with the objective of achieving high functionality without sacrificing ease of use. Since the system is to be used by a meteorologist, attention was given to the design of the user interface. Through menus, windows, graphics, and text, RAPID offers a wide variety of tools that guide the user from the acquisition of the data to the forecast.

In tackling the problem of short term forecasts a distinctive methodology was adopted whereby the task was broken down into functional sub-tasks or modules. Each module processes information received from the previous module and then passes it on to the next module in the chain. Figure 1 provides a schematic representation of how control flows through the individual modules.

## 3. MODULE DESCRIPTION

An earlier description of RAPID by Bohne et al. (1988) provided an overview of many of the modules, however, significant modifications have been introduced since then. For completeness, a brief functional description of each module is provided in this section.

### 3.1 The INGEST Module

The INGEST module has three main functions: to read either satellite or radar data into memory, to scale the data to fit the RAPID color tables, and to display the data on the workstation screen. Input data files processed by RAPID contain images of either 256x256 (GOES IR data) or 512x512 bytes (satellite visible, radar reflectivity and radar velocity data). All data are reduced to 256x256 bytes in order to cut down on the computation time needed

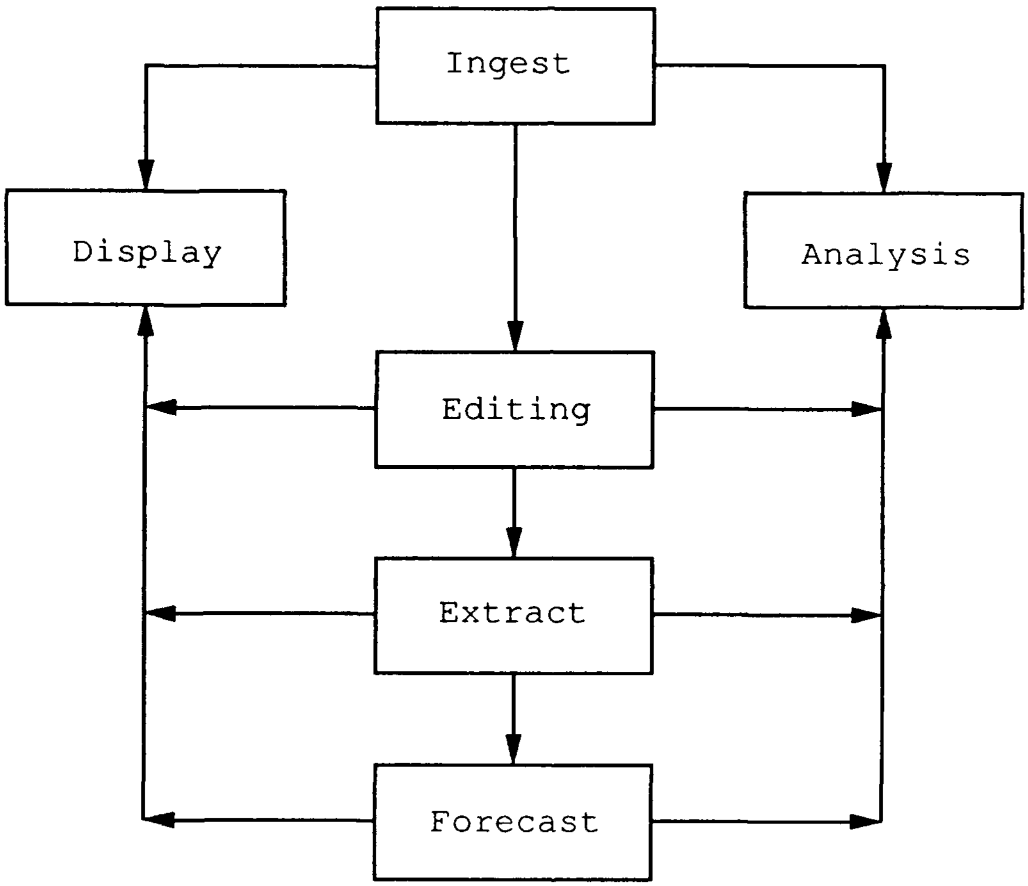


Figure 1. Diagram of control flow through the RAPID modules.

by the various modules. This reduction is obtained by sampling every other column and every other row of a 512x512-byte data file.

The radar data are obtained from the LYR Doppler radar (located in Sudbury) with a spatial resolution of 2x2 km per data point. A RAPID pre-processing unit operates on the raw data by converting it from spherical into Cartesian coordinates.

Geostationary satellite data are available in real-time every 30 minutes through a direct link to the Air Force Interactive Meteorological System (AIMS). AIMS has a direct readout GOES groundstation capable of receiving and storing VAS imagery in satellite scan coordinates. The satellite data are converted into Cartesian coordinates by a second RAPID pre-processing unit. AIMS data file images are normally centered on Bedford, MA, but can be centered on any Service A observing station within the line of sight of the satellite.

### 3.2 The EDITING Module

Frequently it is necessary to precondition data acquired through the INGEST module before it is analyzed. Some data processing modules are sensitive to noise, missing lines, or too many small scale (comparable to the sampling resolution) features in the data. The EDITING module allows the user to interactively filter and smooth the data to remove unwanted features. The available options on the EDITING menu are given in Figure 2.

In signal processing, a filter is a mathematical function used to smooth, enhance, or in some other way modify the appearance of an image. In RAPID, each filter is characterized by a geometric shape or window that defines the domain of the function. The filter operates by replacing the center value of the window domain with the mean or median of all values in the window. A filter can be passed over the entire image once or repeatedly to remove noise, to fill data gaps, or to smooth boundaries.

The functions of the different filters listed in Figure 2 are as follows. The 5x1 vertical median filter (option 1) is used to eliminate missing scan lines and is often used with satellite data. The 9x1 vertical median filter (option 2) is similar to the 5x1 filter but gives a smoother result.

```
 1.  Vertical 5X1 median filter
 2.  Vertical 9X1 median filter
 3.  3X3 box median filter
 4.  5X5 box median filter
 5.  Lowpass filter
 6.  Laplace filter

 8.  Linear shift
 9.  Histogram

11.  Find average intensity of image
12.  Find area of image

 0.  Return to main menu
-1.  Exit
```

Figure 2. The editing module menu.

The 3x3 box median filter (option 3) is used to remove noise spikes in radar data and to smooth boundaries. It is the most commonly used filter for images processed by the RAPID system. The 5x5 box median filter (option 4) is similar to the 3x3 box median filter but gives a smoother result.

The lowpass filter (option 5) removes high frequency features in an image and is used for the suppression of noise at small spatial scales.

The Laplace filter (option 6) computes the average of the 8 points neighboring the center point of a 3x3 box. If the value of the center point is different from the mean of its neighbors the point is displayed in white, otherwise in black. This filter provides a good visual representation of the location of edges and high frequency noise present in the image.

A linear shift (Option 8) changes the intensity of the data by a constant value input by the user. Linear shifting is often done to enhance the visibility of the data to be displayed. A frequency distribution histogram analysis (Option 9) provides a graphical representation of the distribution of features in the data that is easily understood by the user. The final two options for computing average pixel intensity (Option 11) and area (Option 12) are used to characterize the points above a particular threshold value determined by the user.

Options 7 and 10 are currently unused.

### 3.3 The EXTRACT module

After an image has been edited, it is contoured by threshold level. The contour thresholds can be interpreted as gradients of cloud temperature or precipitation intensity. For satellite infrared and radar reflectivity images, the number of threshold levels applied to the data is fixed at 24 and 6 respectively.

The process of contour extraction is completely automated; starting from the highest threshold and working down, the contours are extracted for each level and stored in a data file. The extraction procedure changes the image from a pixel representation into a contour representation wherein every contour is identified by a threshold or level of intensity, a starting point in Cartesian coordinates, a directional code, and the length of this code.

This representation, developed by Freeman (1961), is referred to as Freeman Chain Code (FCC). It enables the user to reduce the size of an image file with a minimum of information loss. For example, an IR image of 256x256 bytes (about 65k bytes) can be represented on average by ~100 contours, each with average length of ~100 elements (about 10k bytes in FCC representation).

Some loss of information occurs during the contour extraction procedure due to the order in which the contours are processed. Contours of highest threshold are extracted first and, after a contour has been located and extracted, all the points inside that contour are reset to the next lower threshold value. In the situation that a contour of lower threshold is contained inside a contour of higher threshold, the lower threshold contour is lost (Figure 3).

Once in FCC representation, the images are stored on disk for two reasons: first, to build a library of case studies, and second, because individual contours need to be accessible by the next module in the analysis scheme. The contours can be accessed more economically and easily if stored in sequential data files rather than in memory.

### 3.4 The FORECAST module

Once the data files have been changed from pixel to FCC representation, the contours are ready to be tracked and forecast by the FORECAST module. Tracking is a manual process through which the user selects three contours from a time sequence of three images. The contours saved in chain code format are read from disk, reconstructed, and displayed on the workstation screen. Through use of the mouse, the user interactively selects the contours to be tracked and forecast. After an initial contour has been chosen, the corresponding contours are selected from the subsequent images in the time series. The later contours represent the changes that the original contour has undergone in shape and position over time. Care must be taken so that the selected contours represent a time series of the same phenomenon. Automatic tracking routines exist for radar and satellite data, but they are beyond the current scope of the project.

Currently, the user has a choice of two forecast techniques that can be applied to the tracked contours. One of these techniques, the Angle Displace-

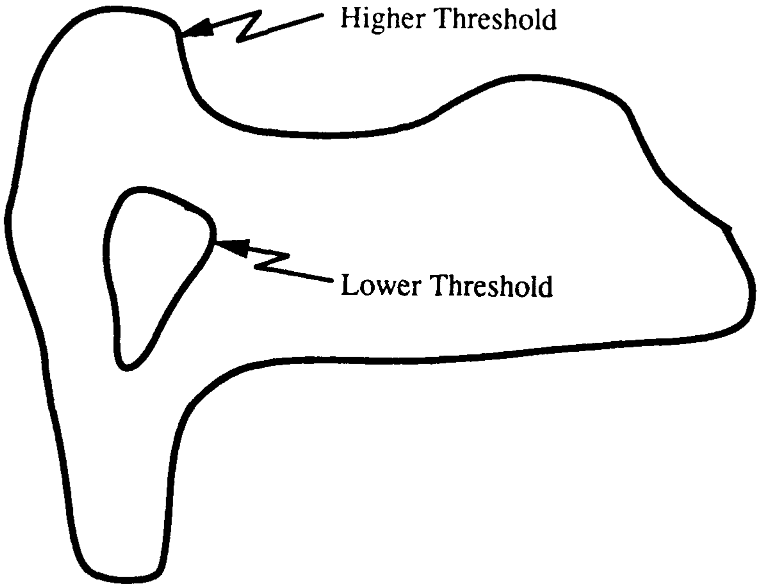


Figure 3. Sample contour with a small area of lower threshold inside an area of larger threshold. The smaller area is lost during the extraction procedure.

ment forecast technique, can be run by RAPID on the selected contours. The other technique, the Whole Contour method, runs as an independent program. For this second technique, the contours tracked by the user in the RAPID FORECAST module are stored on disk in a data file and are later accessed by the Whole Contour program.

### 3.5 The DISPLAY and ANALYSIS modules

The DISPLAY and ANALYSIS modules are accessible by all the other modules. The DISPLAY module is used to display images on the workstation screen. The ANALYSIS module contains functions to help the user to better understand the data. For example, one ANALYSIS function returns the plotted histogram of the data; another returns the results of statistical analysis performed on the data to be extrapolated.

## 4. THE FORECAST TECHNIQUES

Two forecast techniques have been developed to predict the motion and shape evolution of selected contours: the Angle Displacement technique and the Whole Contour method. Both forecast techniques approximate a cloud or precipitation boundary with a set of attributes. The attribute trends obtained from a time series of satellite or radar images are then extrapolated to produce a set of predicted "forecast attributes". Forecast attributes are then used to construct the predicted contour boundary shape and location. While both techniques forecast the movement and shape development of the contours through trend extrapolation, they differ in the choice of attributes to be forecast.

The whole contour method has undergone preliminary testing. Initial results of this evaluation are reported by Heideman et al. (1990), and provide an estimate of the forecast accuracy. Test results also indicate the set of input parameters which produce the optimum forecast.

### 4.1 Angle Displacement Method

The original concept for the angle displacement forecast technique was suggested by Kavvas (1988). The following sections provide a description of the technique and of the algorithm as implemented on RAPID.

#### 4.1.1 Description

The Angle Displacement method uses two attributes to identify and characterize a contour boundary:

1) the centroid (the average of the x and y coordinates of the points on the boundary) and

2) some number of segments (n) joining points on the contour with the centroid.

A 360 degree angle can be divided into an arbitrary number of equal angles ($\alpha$). The number of segments, n, is approximately equal to $360/\alpha$. The first segment starts at the centroid and ends on the boundary at a zero displacement angle, the second segment starts at the centroid and ends on the boundary at an angle zero + $\alpha$, and so on. Figure 4 shows an example of a contour approximated by 8 segments using a 45 degree displacement angle.

To summarize:

| | |
|---|---|
| segment 1 | displacement angle = 0 |
| segment 2 | displacement angle = $\alpha$ |
| segment 3 | displacement angle = $2*\alpha$ |
| | $\vdots$ |
| segment n | displacement angle = $(n-1)*\alpha$ or $(360-\alpha)$ |

Figure 5 shows examples of contours where the number of segments associated with a given displacement angle varies from contour to contour. Note that in Figure 5a there is only 1 segement length associated with the angle whereas in Figure 5b there are 3 (one for each point the segment crosses the contour boundary). This figure demonstrates why the number of segments (n) is approximately and not exactly equal to $360/\alpha$.

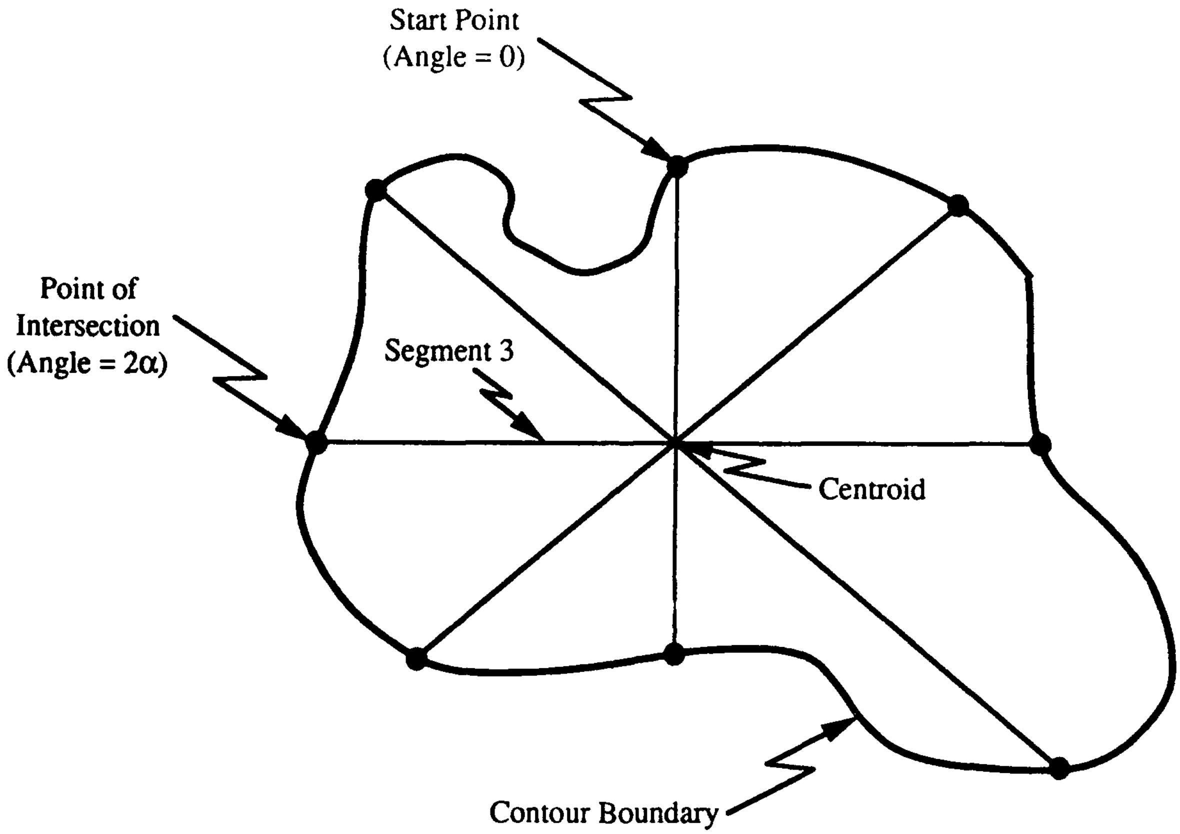


Figure 4. Example of a contour approximated by 8 points using a displacement angle of 45 degrees.

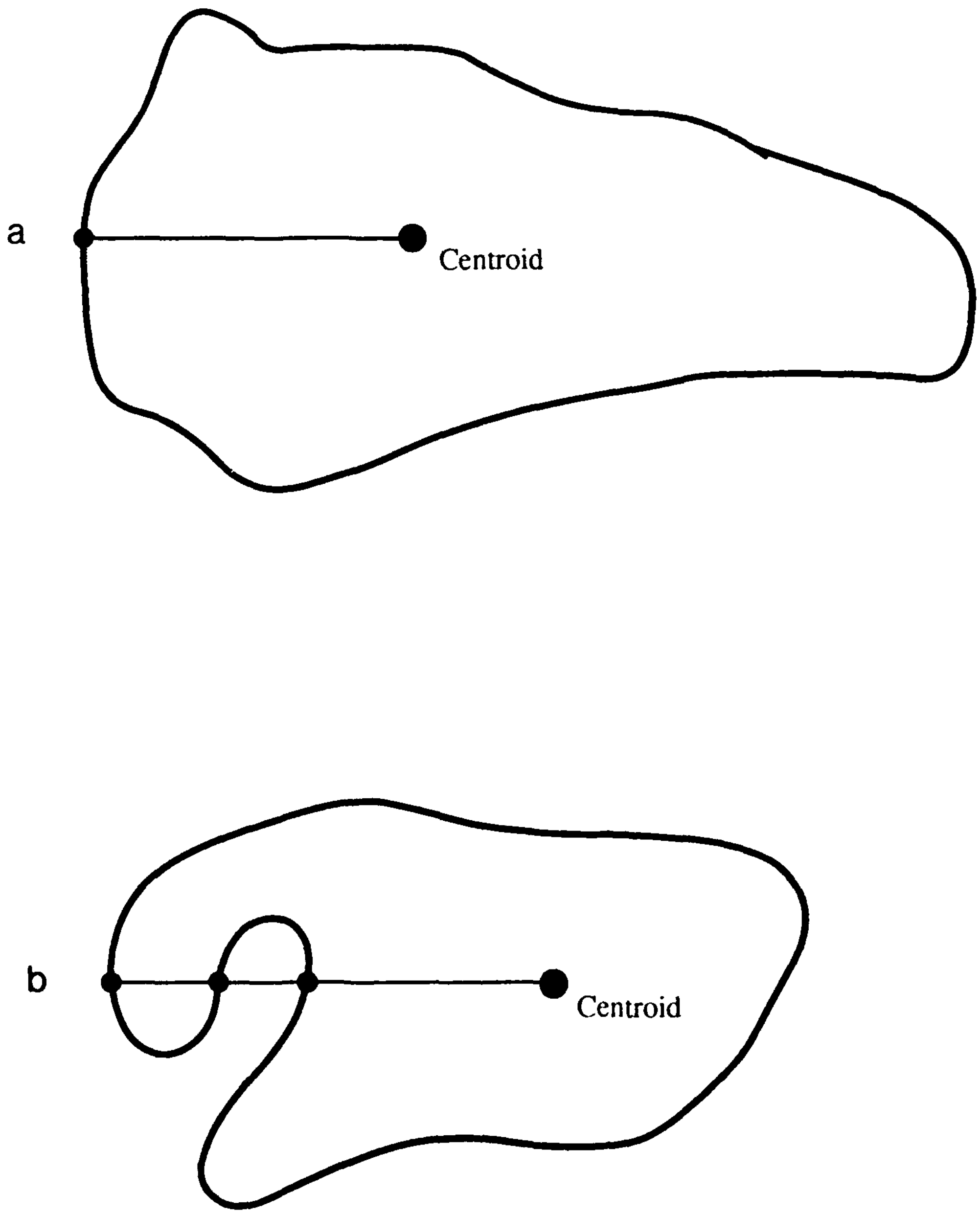


Figure 5. Examples of two contours with different numbers of segments associated with the same displacement angle; (a) 1 segment length, (b) 3 segment lengths.

These attributes (the centroid and segments) are extracted from each contour in a time series of contours that have been identified during the tracking process. Then, the location of each centroid is linearly extrapolated to determine the coordinates of the centroid of the forecast contour. The slope and intercept for the linear extrapolation are calculated from a linear least squares fit of the three values in the time series as follows:

$$\text{slope} = \frac{\Sigma x_n^2 \Sigma y_n - \Sigma x_n \Sigma x_n y_n}{k\Sigma x_n^2 - (\Sigma x_n)^2}$$

$$\text{intercept} = \frac{k\Sigma x_n y_n - \Sigma x_n \Sigma y_n}{k\Sigma x_n^2 - (\Sigma x_n)^2}$$

where x and y are the centroid coordinates and k is the number of timesteps (recall from Section 3.4 that the contour was tracked at three time steps.) The segment lengths for each displacement angle are extrapolated in a similar way to produce the forecasted segment lengths. The forecast boundary is then constructed from the forecasted attributes.

Even with this simple forecast technique, implementation presents problems for complicated shapes (e.g. centroid outside the boundary, or multiple segments associated with a given displacement angle).

### 4.1.2 Algorithm

The algorithm works on a sequence of three contours and approximates each contour by using a displacement angle of 10 degrees. These parameters are hardwired in the program, but can easily be set to different values. The sequence of contours was set to three so that the workstation screen could be divided in four visible frames, the first three of which display the observations while the fourth displays the forecast. Following a testing period, a displacement angle of 10 degrees was chosen. This represents a compromise because it identifies enough points on the contour so that the main shape characteristics of the contours are retained without adding an undue

computational burden. Displacement angles down to 0.5° were tested with no significant improvement in the representation of the contour. Recall that the sequence of contours to be used by the forecast technique is selected manually by the user during the tracking process.

For the displacement angle of 10 degrees, segment lengths to all the points on the contour at angles which are exact multiples of 10 (0, 10, 20, ... 350) are computed. Recall from Section 3.3 that contour boundaries are maintained in FCC notation which is a series of discrete direction codes based on a regular Cartesian grid. Frequently, a line segment projected out from the contour centroid at a fixed displacement angle will intersect the contour boundary somewhere other than at a grid point location. To compute the segment length in this situation it is necessary to interpolate between calculated segment lengths projected to the two adjacent grid points which bracket the point of intersection.

From each contour, the centroid (the first attribute) and the lengths of the segments (the second attribute) are stored. The segment lengths are maintained in a two-dimensional array as described in Table 1. Lengths associated with the first contour of the time sequence are stored in the first 10 rows (labeled 0-9 in the figure), those for the second contour are stored in the next 10 rows (10-19), and so on. The fact that each contour is assigned 10 rows implies that a maximum of 10 segments can be associated with any displacement angle.

From Table 1 it can be noted that for a displacement angle equal to 0 (column 0), the first contour has three associated segments (row 0, 1, and 2). For the same angle 0 (column 0), the second and third contours have only two associated segments, stored respectively at rows 10, 11 and 20, 21. Similarly, all the segments of the three contours at an angle of 20 degrees ($2*\alpha$) are stored in column 2. At this angle, the first contour has four associated segments and their values are stored in rows 0, 1, 2 and 3.

Table 1 does not contain any information on the order in which segment lengths are stored. Ambiguities can occur when the extraction algorithm produces multiple segment lengths for a given displacement angle (e.g., contours with hook or looping shapes as in Figure 5b). In this case, the order that the lengths are stored in the table are not in the same sequence in

**Table 1**

**Representation of contours in memory for a fixed displacement angle ($\alpha$=10°)**

| | | col 0 (0) | col 1 ($\alpha$) | col 2 ($2*\alpha$) | ... | col 35 ($35*\alpha$) |
|---|---|---|---|---|---|---|
| | row 0 | 10 | 12 | 9 | | 13 |
| | row 1 | 8 | 4 | 2 | | |
| | row 2 | 6 | | 15 | | |
| Contour 1 | row 3 | | | 18 | | |
| | row 5 | | | | | |
| | ⋮ | | | | | |
| | row 9 | | | | | |
| | row 10 | 8 | | | | |
| Contour 2 | row 11 | 6 | | | | |
| | ⋮ | | | | | |
| | row 19 | | | | | |
| | row 20 | 8 | | | | |
| | row 21 | 6 | | | | |
| Contour 3 | ⋮ | | | | | |
| | row 29 | | | | | |

which they are extracted from the contour. Therefore a second table is maintained to provide the proper sequence for extracting the segment lengths from Table 1 to correctly reconstruct the contour. Table 2 contains a one dimensional array in which each element points to a specific segment length in Table 1. The order in which the elements are stored in Table 2 provides the proper sequence for reconstruction of the contour shape. For the example in Tables 1 and 2, the value of 2 in row 0 of Table 2 indicates that the 3rd element in Table 1 (the first element has an index of zero) is the first segment length of the contour. The value of the 3rd element in Table 1 gives the length of the segment (9) while the corresponding column gives the displacement angle (20 degrees). The next element in Table 2 points to the next segment moving around the contour, and so on. A value of 36 in Table 2 wraps around from the end of row 0 (col 35) in Table 1 to the 1st element in row 1 (i.e. row 1, col 0) which, in this example, is a segment of length 8 at

**Table 2**

**Table of positions**

| | |
|---|---|
| row 0 | 2 |
| row 1 | 4 |
| row 2 | 5 |
| row 3 | 4 |
| row 4 | 56 |
| ⋮ | |
| row 55 | 35 |
| row 56 | 36 |
| ⋮ | |

0 degree displacement. The number of points that approximate the contour (the length of the table) is stored as well.

Through application of the linear extrapolation technique (Section 4.1.1) to the stored attribute information (centroids and segments) the forecast is made.

Depending on the change in the shape of the contours, different scenarios must be considered when forecasting the segments. In Section 4.1.1 (Figure 5b) the situation was described wherein more than one line segment can exist at a single displacement angle. Table 3 lists the number of segments at a given displacement angle for two different hypothetical scenarios.

**Table 3**

**Scenarios to be taken into account when forecasting contour attributes**

| | contour 1 | contour 2 | contour 3 |
|---|---|---|---|
| Scenario 1: | x† | x | x |
| Scenario 2: | xx | xxx | xxxx |

†Each x represents one line segment associated with a given displacement angle.

**Scenario 1**: All three contours in the time series have exactly one segment associated with the given angle (see Figure 5a). The segment lengths are extrapolated to produce a single forecasted segment length.

**Scenario 2**: Multiple segments are found for the fixed displacement angle (see Figure 5b). The first contour has two associated segments, while the second contour has three, and the third contour has four. In general this occurs when an unequal number of associated segments are found for a given angle. This situation is not the most common one, and it must be treated differently than the first scenario.

Since the second scenario introduced additional database handling problems and complicated a technique that was chosen for its simplicity, it was decided not to use those points that fall within the second scenario. Whenever the observed contours have an unequal number of segments for a given angle, the associated segment is not forecast and the algorithm moves to the next angle.

### 4.2 The Whole Contour Technique

The Whole Contour Technique is based on Fourier analysis of the extracted contours (Bohne et al., 1988). Using Fourier analysis, any periodic function can be expressed as a sum of trigonometric functions with specified amplitudes and phases. Each point on a contour can be described by its Cartesian coordinates (x,y), and the functions describing the contour can be parameterized in terms of the path length starting at an arbitrary point and walking counterclockwise around the contour. The functions that express the x and y variation are periodic with a period equal to the length of the contour. Therefore, any contour can be expanded into two associated functions, $F_x(j)$ and $F_y(j)$, where j is the j'th point of the x or y component along the contour. Plots of the variations of x and y for a sample contour given in Figure 6 are shown in Figures 7a and 7b. Through Fourier analysis, the amplitudes and/or phases of the above functions are obtained, and they are used as the attributes to be forecast. From all the forecasted attributes, the forecasted contour is reconstructed.

The following section includes a general description of the Whole Contour technique, the characteristics of the computer program, an example about how to use the program, and a discussion of the performance of the Whole Contour technique in forecasting the evolution of the contour.

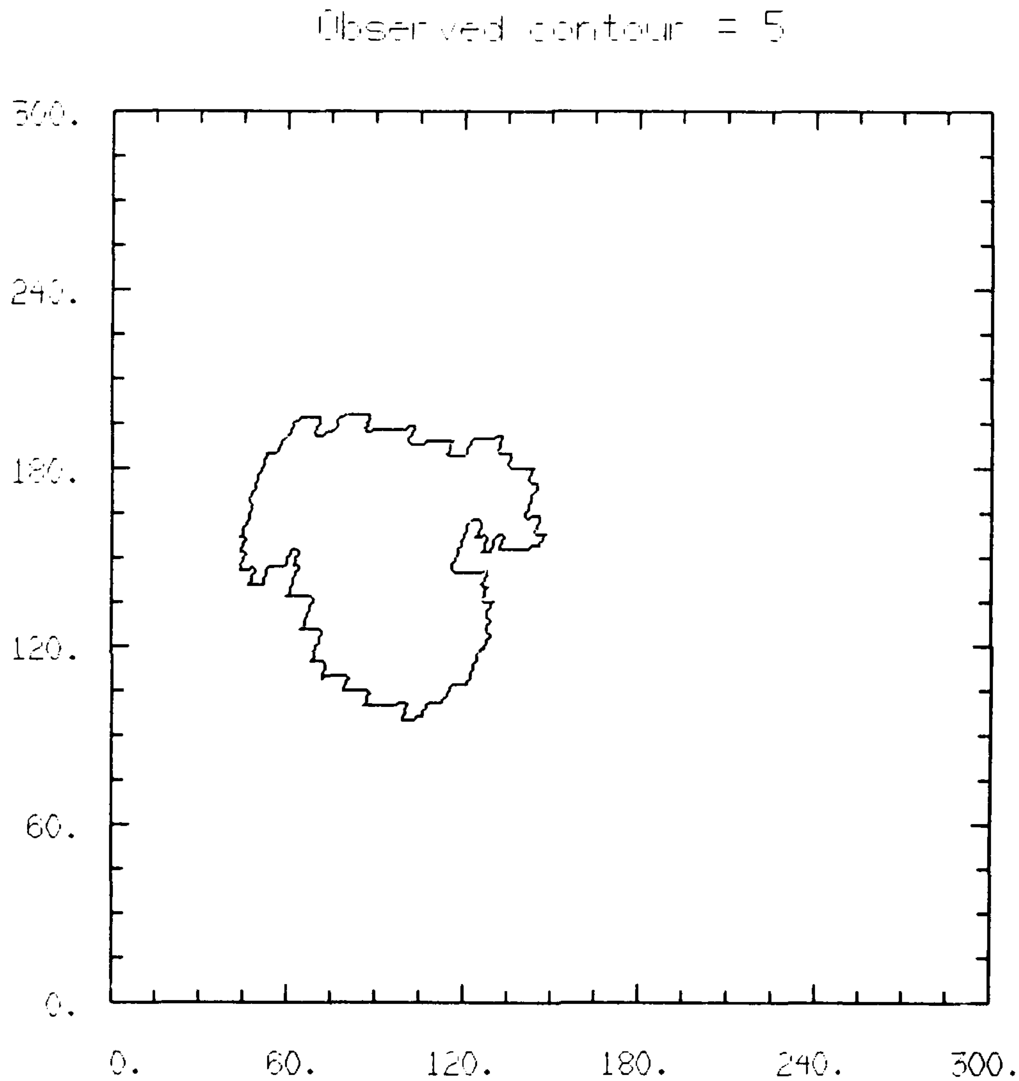


**Figure 6.** A sample contour representative of those obtained by the RAPID extract module from either GOES IR imagery or radar reflectivity data overlaid on an X-Y grid.

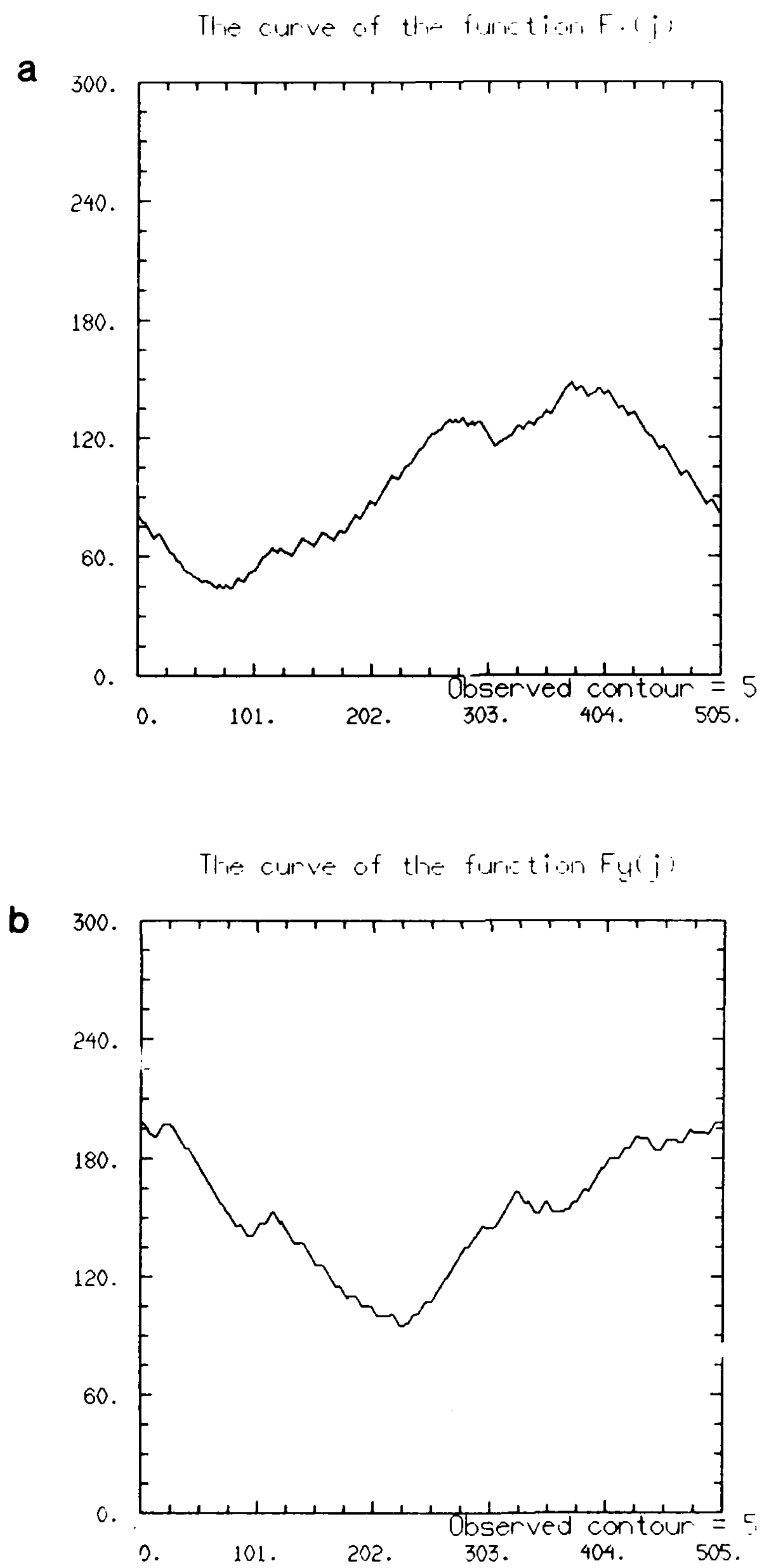


**Figure 7.** The functions $F_x(j)$ and $F_y(j)$ for the contour shown in Figure 6: (a) $F_x(j)$, (b) $F_y(j)$.

### 4.2.1 Theoretical Background

Applying the Fourier transformation to $F_x(j)$ and $F_y(j)$, the following functions are obtained

$$f_x(k) = \int_{-\infty}^{\infty} F_x(j) e^{i2\pi kj} dj,$$

$$f_y(k) = \int_{-\infty}^{\infty} F_y(j) e^{i2\pi kj} dj,$$

where k is the number of a specific Fourier component (wave number). The discrete Fourier Transformations become

$$f_x(k) = \sum_{j=1}^{M} F_x(j) e^{i\frac{2\pi k}{M}(j-1)} \quad . \; .$$

$$f_y(k) = \sum_{j=1}^{M} F_y(j) e^{i\frac{2\pi k}{M}(j-1)} \quad . \; .$$

where M is the number of points along the contour.

The amplitudes of the Fourier component k of the functions $F_x(j)$ and $F_y(j)$ are

$$A_x^k = \left[ f_x(k) f_x^*(k) \right]^{1/2}$$

$$A_y^k = \left[ f_y(k) f_y^*(k) \right]^{1/2}$$

where $f^*(k)$ is the conjugate of the complex number $f(k)$. The phases of the Fourier component k of the functions $F_x(j)$ and $F_y(j)$ are

$$P_x^k = \tan^{-1}\left[\frac{Im(f_x(k))}{Re(f_x(k))}\right] ,$$

$$P_y^k = \tan^{-1}\left[\frac{Im(f_y(k))}{Re(f_y(k))}\right] ,$$

where Im(f(k)) and Re(f(k)) are the imaginary and real parts of the complex number f(k) respectively.

Figures 8a and 8b show the amplitudes of the first 30 Fourier components for the curves given in Figures 7a and 7b. Since the contours that are used to produce the forecast and the forecast itself have different lengths, their $F_x(j)$ and $F_y(j)$ functions have different periods. In order to circumvent this problem, the amplitudes are normalized by dividing by the length of the corresponding contour:

$$A^k = \frac{1}{M}\left[f(k)f^*(k)\right]^{1/2}$$

Figures 9a and 9b show the normalized amplitudes for different Fourier components. Hereafter all the normalized amplitudes will be referenced as amplitudes.

In this way, the period equals 1 for each contour. The forecast amplitude, later to be used to reconstruct the forecast contour, is obtained by multiplying the normalized forecast amplitude by the number of forecast points. The amplitude and phase in x and y,

$$A_x^k , A_y^k , P_x^k , P_y^k ,$$

are the basic elements used to describe the contour, compose the forecast attributes and reconstruct the forecast contours.

### 4.2.2 Forecast Attributes

A forecast attribute is a parameter chosen to predict the contour shape and location at some future time based upon its past history. The following

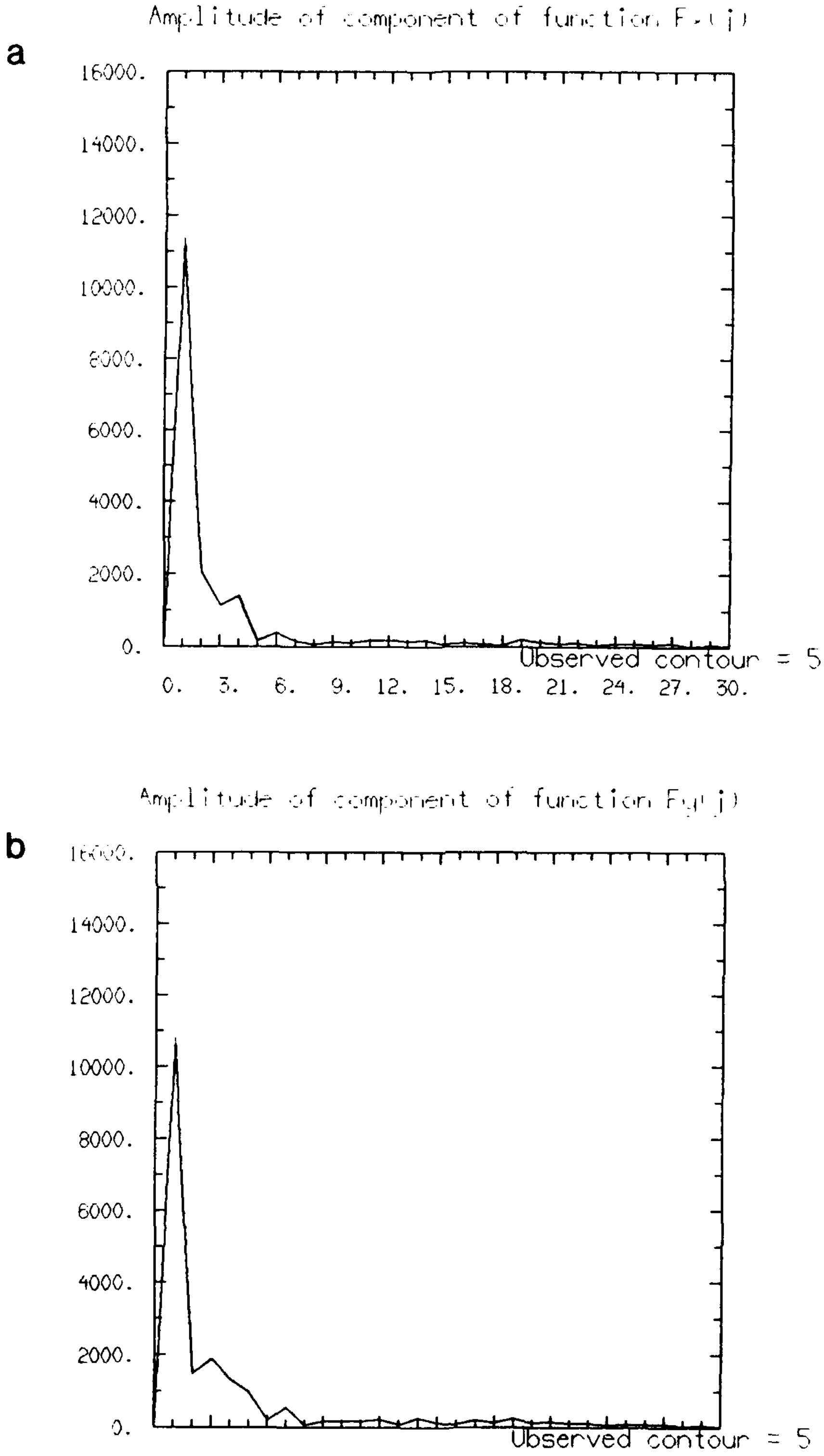


**Figure 8.** **Amplitudes of the first 30 fourier components of the functions in Figures 7a and 7b:** (a) components of $F_x$, (b) components of $F_y$.

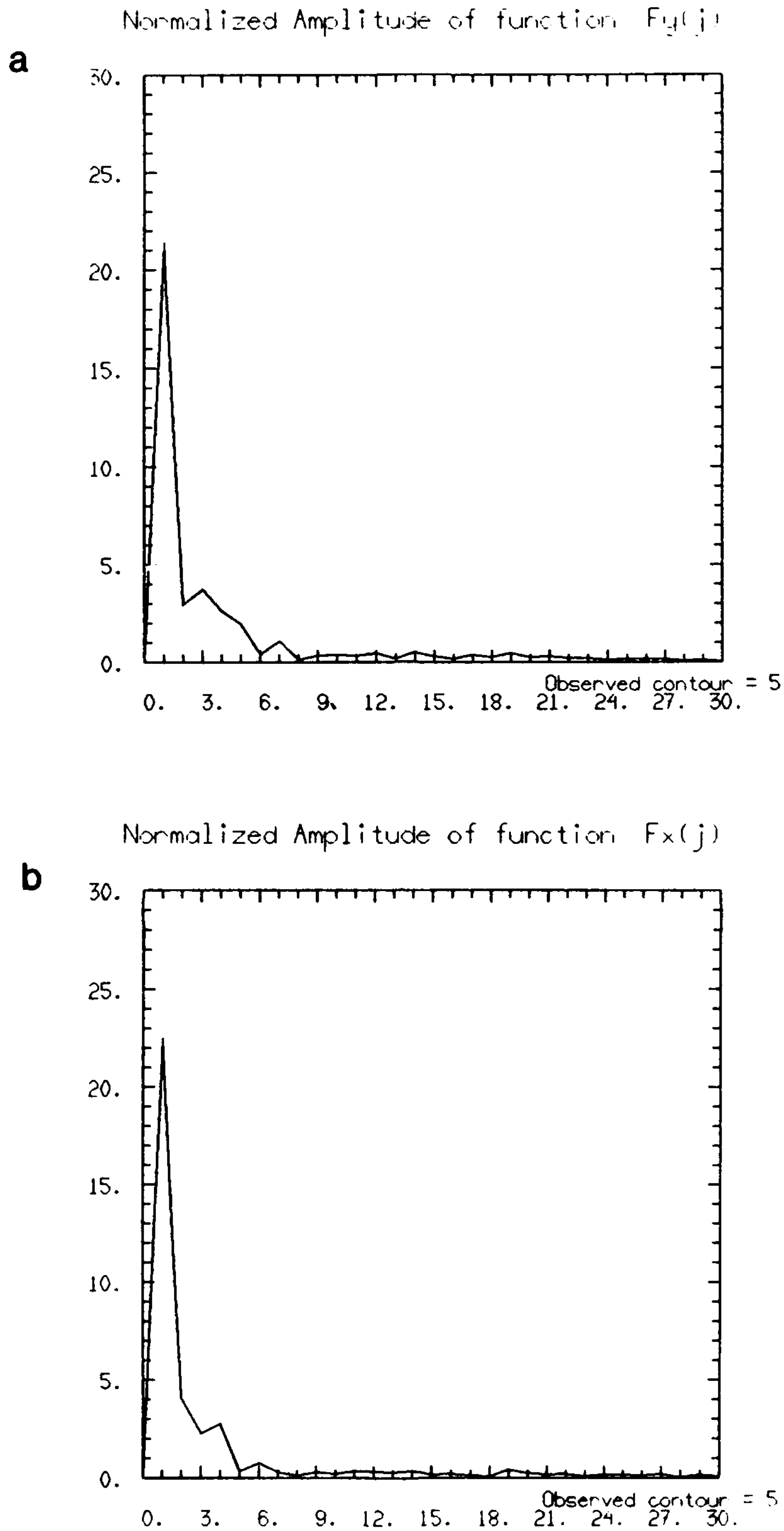


**Figure 9.** **Normalized amplitudes for the first 30 fourier components of the functions in Figures 6a and 6b: (a) components of $F_x$, (b) components of $F_y$.**

subsections briefly describe the different forecast attributes which have been chosen.

#### 4.2.2.1 x_centroid and y_centroid

The x_centroid ($X_0$) and y_centroid ($Y_0$) are given by the following formula

$$X_0 = \frac{1}{M} \sum_{j=1}^{M} x_j \quad , \quad Y_0 = \frac{1}{M} \sum_{j=1}^{M} y_j \quad .$$

#### 4.2.2.2 Aspect Ratio

The aspect ratio ,$\gamma$, is defined as the ratio of the contour extents along the x and y axes respectively

$$\gamma = \frac{X_{max} - X_{min}}{Y_{max} - Y_{min}} ,$$

where $X_{max}$ and $X_{min}$ are the maximum and minimum values of x along the contour, respectively. Similarly, $Y_{max}$ and $Y_{min}$ are the extremes of y along the contour.

This forecast attribute is used to force the forecasted contour to retain a similar shape to that of observed contour. The values of points (x,y) which are computed by the forecast algorithm are scaled according to the forecasted value of aspect ratio $\gamma^f$

$$\gamma^1, \gamma^2, \ldots, \gamma^{t-1} \rightarrow \gamma^f .$$

The values of x are scaled such that the aspect ratio calculated from ($x_s$,y) is equal to the forecasted value of aspect ratio, where $x_s$ is the value of x after being scaled. If the aspect ratio calculated from (x,y) is $\gamma^c$, the scale factor SF is

$$SF = \frac{\gamma^f}{\gamma^c} ,$$

and

$$x_{js} = SF \cdot x_j \qquad j = 1,2, \ldots, M.$$

#### 4.2.2.3 Area

The area is calculated from the equation

$$\text{area}(x,y) = \frac{1}{2} \left| x_M y_1 - x_1 y_M + \sum_{j=1}^{M-1} (x_j y_{j+1} - x_{j+1} y_j) \right| .$$

This forecast attribute forces the forecasted contour to retain its proper areal coverage. If area$(x_s,y)$ represents the area calculated from scaled forecasted values $(x_s,y)$, and the forecasted value of the area is represented by area$(x,y)^f$, then the program will scale both the values of $x_s$ and y according to the values of area$(x,y)^f$ and area$(x_s,y)$. The scale factor SF becomes:

$$SF = \frac{\text{area}(x,y)^f}{\text{area}(x_s,y)} ,$$

and

$$\tilde{x}_j = SF \cdot x_{js} \qquad j = 1,2, \ldots, M \quad ,$$

$$\tilde{y}_j = SF \cdot y_j \qquad j = 1,2, \ldots, M \quad ,$$

where $\tilde{x}_j$ and $\tilde{y}_j$ are the values of the j'th point of x and y after being scaled by area, respectively.

#### 4.2.2.4 Amplitude and Phase

The amplitude and phase can be treated as individual forecast attributes, or the forecast attributes can be combinations of amplitudes and/or phases. Since the amplitudes and phases are the basic information which are needed to reconstruct the contour, the combination should be selected carefully. For example, the forecasted attributes can be

$$A_x \quad , \quad A_y - A_x \ , \ P_x \ , \ P_y - P_x$$

or they could be

$$A_x \ , \ (A_y - A_x)P_x \quad , \quad P_x \quad , \ (P_y - P_x)A_x$$

for all the different Fourier components.

Although we do not directly forecast the amplitude and phase in y of different Fourier components, we can still derive their forecast values. For example, in the first case

$$\text{Let } A_y' = A_y - A_x \quad , \ P_y' = P_y - P_x \ .$$

If the forecast values are denoted as

$$\tilde{A} \quad , \tilde{P} \quad ,$$

then we have the forecast value of the amplitude and phase in y;

$$\tilde{A}_y' = \tilde{A}_y - \tilde{A}_x \quad , \quad \tilde{P}_y' = \tilde{P}_y - \tilde{P}_x \quad ,$$

$$\tilde{A}_y = \tilde{A}_y' + \tilde{A}_x \quad , \quad \tilde{P}_y = \tilde{P}_y' + \tilde{P}_x \quad .$$

The rationale for choosing different combinations of amplitudes and phases is explained in Section 4.2.4. The analysis performed during the developoment phase leads us to believe that other combinations may improve the forecast accuracy. Additional testing needs to be performed to determine the optimal combination of amplitudue and phase.

#### 4.2.3 Prediction Equation

The values of the forecasted attributes are extrapolated to produce a forecast value. The prediction equation has the following general form:

$$FA^t = C_0 + C_1 t + C_2 t^2 + \ldots + C_n t^n. \qquad (4.1)$$

where FA is the value of specific forecast attribute at forecast time t and n is the order of the prediction equation. $C_0$, $C_1$, $C_2$, ..., $C_n$ are the coefficients derived from solving the equation with the values of $(FA^1,1)$, $(FA^2,2)$, $(FA^3,3)$ ..., and $(FA^{n+1},n+1)$. After the values of these coefficients have been obtained, Eq. 4.1 can be used to derive the forecast value at any given time t, $FA^t$. The order of the polynomial is a parameter input by the user.

### 4.2.4 Method Code

Many forecast attributes have been chosen and tested during the algorithm development phase. From the test results, four different sets of forecast attributes have been selected, each of which is referred to as a method. For a list of the forecast attributes, see Table 4.

The first method uses the following attributes: the center of the contour, the square root of area covered by the contour, the number of points in the contour, the amplitudes, and the phases. Since the first few amplitudes and phases account for most of the information in the Fx or Fy functions, only a selected number of amplitudes and phases are used. The number of the components to be used is an input parameter. The second method adds the aspect ratio as an additional variable to those used in the first technique. The evolution of the amplitude or phase of a specific Fourier component in the first two methods depends only on its own previous time history and is not affected by the evolutions of the other Fourier components.

In the atmosphere, different weather systems have different spatial scales, and the energy of different scales will be transferred to other scales through the different atmospheric motions. Since a contour can be separated into waves of different wave number, it is assumed that the evolution of one Fourier component is related to the evolution of other components.

The reason for choosing the forecast attributes of the amplitudes and phases for methods 3 and 4 is to try to understand whether or not the variation of amplitudes or phases of one Fourier component are dependent on the relationships with the amplitudes and/or phases of the other components. In method 3, it is assumed that the important relationship of amplitude and phase in x and y between the different Fourier components depends on the value of the difference of adjacent components. Because the amplitude of component 1 is much larger than the other components, the values of components 1 and 2 are

Table 4. The list of all the forecast attributes to be used in the different methods.

## The Forecast Attributes

| Method | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Area | Node | $X_0$ | $Y_0$ | | $A_x^1, A_x^2, \ldots, A_x^N$ | $A_y^1, A_y^2, \ldots, A_y^N$ | $P_x^1, P_x^2, \ldots, P_x^N$ | $P_y^1, P_y^2, \ldots, P_y^N$ |
| 2 | Area | Node | $X_0$ | $Y_0$ | $\gamma$ | $A_x^1, A_x^2, \ldots, A_x^N$ | $A_y^1, A_y^2, \ldots, A_y^N$ | $P_x^1, P_x^2, \ldots, P_x^N$ | $P_y^1, P_y^2, \ldots, P_y^N$ |
| 3 | Area | Node | $X_0$ | $Y_0$ | $\gamma$ | $A_x^1, A_x^2, A_x^3-A_x^2, \ldots, A_x^N-A_x^{N-1}$ | $A_y^1, A_y^2, A_y^3-A_y^2, \ldots, A_y^N-A_y^{N-1}$ | $P_x^1, P_x^2, P_x^3-P_x^2, \ldots, P_x^N-P_x^{N-1}$ | $P_y^1, P_y^2, P_y^3-P_y^2, \ldots, P_y^N-P_y^{N-1}$ |
| 4 | Area | Node | $X_0$ | $Y_0$ | $\gamma$ | $A_x^1, A_x^2/A_x^1, \ldots, A_x^N/A_x^{N-1}$ | $A_y^1, A_y^2/A_y^1, \ldots, A_y^N/A_y^{N-1}$ | $P_x^1, P_x^2/P_x^1, \ldots, P_x^N/P_x^{N-1}$ | $P_y^1, P_y^2/P_y^1, \ldots, P_y^N/P_y^{N-1}$ |

Node : The total number of points of the contour.
$X_0$ : The x coordinate of the centroid.
$Y_0$ : The y coordinate of the centroid.
$\gamma$ : The aspect ratio.
$A_x^k, A_y^k$ : The amplitude of the Fourier component k in x and y, respectively.
$P_x^k, P_y^k$ : The phase of the Fourier component k in x and y, respectively.
N : The number of the Fourier components to be used to reconstruct the forecast contours.

used as basic forecast attributes, and the differences are computed starting from component 3.

Method 4 uses the ratio of the amplitude of component k+1 to the amplitude of component k as the forecast attribute. As can be seen from Figures 9a and 9b, the amplitudes of higher wave numbers decreases with wave number. Therefore, the value of the forecast attribute becomes very large as the denominator of the ratio approaches zero. For example, if the observed amplitude of component $A_k$ is nearly zero, then the value of forecast attribute $A_{k+1}/A_k$ becomes very large. If the forecast value of $A_k$ is not small, then the forecast value of $A_{k+1}$ will be too large and the whole forecast will fail. In order for the method to work, some constraints have to be introduced: (1) the amplitude of the higher wave number is not allowed to be more than twice the amplitude of the previous wave number (that this is seldom the case can be seen from Figures 9a and 9b), and (2) if the amplitude of the denominator of the ratio (e.g. $A_k$) is less than 0.001, the value is set equal to 1. This is because the amplitudes are very small and roughly equal for higher wave numbers.

In order to maintain the proper shape and area of a forecast contour, a modification is performed on the forecasted contours. The values of (x,y) will be scaled only by area in method 1, but they will be scaled both by the aspect ratio and area in methods 2, 3 and 4.

In some cases, especially when a higher order of the prediction equation is used, the forecasted value of the number of points or the area will either be too large or too small. If the forecast value of the area is negative, the program will treat the forecast as a failed forecast and the output will be the forecast of the centroid $(x_0,y_0)$. If the forecast of the number of points becomes zero or negative the program will check for a forecasted value of the area less than zero. If the forecast value of the area is less than zero the output will be the forecast of the centroid $(x_0,y_0)$, otherwise the number of points will be given a value of 10. If the value of the number of points is larger than 2048 it will be reassigned as the value of 2048. These limits on the number of points are imposed to prevent unreasonably large or small numbers from causing the forecast equation to "blow up" when a second order (or higher) polynomial is used. If the absolute value of the point in x or y

is larger than 32768 (an arbitrarily large number outside the expected domain), the program will treat the forecast as a failed forecast and the output will be the forecast of the centroid $(x_0, y_0)$. If the forecast is a line the output will be the forecast of the centroid $(x_0, y_0)$.

When the forecasted value of the aspect ratio is not positive, the program will skip the process of scaling by the aspect ratio. If the area of the contours after scaling by the aspect ratio is less than 1, the program will skip the process of scaling by the area too. If one of the situations described above occurs during the forecast process, an informational message will appear on the screen to alert the user.

### 4.2.5 Brief Review

The basic idea of the Whole Contour technique is to split the contour into functions of x and y, to obtain the amplitudes and phases in x and y direction, to forecast the attributes of Fourier component k at time t based on its previous observational values (1, 2, ...., (t-1)) and to recompose the selected forecast attributes back to their Fourier components of amplitude or phase:

$$(A_x^k)^1 \;,\; (A_x^k)^2 \;,\; (A_x^k)^3 \;,\; (A_x^k)^4 \;,\ldots\; (A_x^k)^{t-1} \rightarrow (\tilde{A}_x^k)^t \;,$$

$$(A_y^k)^1 \;,\; (A_y^k)^2 \;,\; (A_y^k)^3 \;,\; (A_y^k)^4 \;,\ldots\; (A_y^k)^{t-1} \rightarrow (\tilde{A}_y^k)^t \;,$$

$$(P_x^k)^1 \;,\; (P_x^k)^2 \;,\; (P_x^k)^3 \;,\; (P_x^k)^4 \;,\ldots\; (P_x^k)^{t-1} \rightarrow (\tilde{P}_x^k)^t \;,$$

$$(P_y^k)^1 \;,\; (P_y^k)^2 \;,\; (P_y^k)^3 \;,\; (P_y^k)^4 \;,\ldots\; (P_y^k)^{t-1} \rightarrow (\tilde{P}_y^k)^t \;.$$

After all the forecasted values of amplitude and phase in x and y have been obtained, the inverse Fourier transformation is applied to reconstruct the forecasted contour. Finally, the values of each point of Fx(j) and Fy(j) are calculated with respect to other information (i.e. area, aspect ratio and centroid of the contour), and the forecast contour is obtained.

$$F_x(j)^1 \ , \ F_x(j)^2 \ , \ F_x(j)^3 \ , \ F_x(j)^4 \ , \ \ldots . \ F_x(j)^{t-1} \rightarrow \hat{F}_x(j)^t \ .$$

$$F_y(j)^1 \ , \ F_y(j)^2 \ , \ F_y(j)^3 \ , \ F_y(j)^4 \ , \ \ldots . \ F_y(j)^{t-1} \rightarrow \hat{F}_y(j)^t \ .$$

**4.2.6 The Characteristics of the Display Function**

After the calculation is completed, the program can display the observed and forecast contours on an AMPS workstation screen. It can also display the values of the selected forecast attributes for both the observed and the forecast contours, such as the area, the number of points on the contour, the x and y coordinates of centroid, and the aspect ratio. Besides these values, all the forecast attributes which are in the form of the combination of the amplitudes and phases have been decomposed into the form of amplitudes and phases in x and y, and their values are displayed on the screen too. Hereafter, these display items are referred to as features. The program can perform the different analyses with the same data file, or start over with the new data file. For convenience, there is a routine designed for the output plot of contours or features.

So far the program can allow only ten observed contours and ten forecast contours be plotted into the same frame at a time, but this can be adjusted. The observed contours are plotted using different colors, while the forecast contours are displayed in red. A message will appear at the lower right corner of the screen containing information about the input values of n_pre, n_freq, order, method, and the time of the observed and forecast contours chosen by the user.

The user can also choose the degree of smoothing when displaying the observed contours, with the smaller the input number the smoother the contours. Original contours are viewed by specifying zero or hitting the <return> key. The degree of smoothing used to display the contours does not affect the contour shape used to generate the Fourier components; transformations are always performed on the original, unsmoothed contours.

The contours can be displayed in absolute coordinates since both the x and y coordinates are between 0 to 300. If the user decides not to use absolute coordinates, the program will select a range based on the maximum and minimum values of x and y among the contours shown on the same frame (relative coordinates).

The features plot contains a time sequence of the feature values (i.e. area, the number of points on the contour, the x and y coordinates of centroid, aspect ratio, x_amp, y_amp, x_phase, y_phase). A blue line represents the values of the observed contours and a red line represents the values of the forecast contours.

### 4.2.7 Discussion

The Whole Contour program has great flexibility to perform the forecast with different combinations of input parameters and allows the user to visually compare their effects. After testing the Whole Contour technique on several case studies (Heideman et al., 1990) it appears that the last three methods perform significantly better than the first one. Of these three methods, it is hard to say which one performs the best.

The results show that linear extrapolation, order 1, apparently gives the best forecast. From the features plot, the linear extrapolation does very well in forecasting the area, the number of points of contour, the x and y coordinates of centroid and the aspect ratio. However, if the time history of the values of the forecast attribute oscillates, then the linear extrapolation does not forecast their values properly, especially the phases. A new prediction method should be developed to effectively handle the oscillating situation.

The number of time histories of the contour used in making the forecast is set through the input variable n_pre (i.e., if n_pre is 3, then the contour is tracked through 3 time steps). Although the later contours contain more important information than the earlier ones in forecasting the contour, in the case where the attribute oscillates, a value of n_pre = 2 or 3 will produce a diverging forcast. A value of n_pre = 4 produces a forcast closer to the mean and is generally more successful. In the case where the attribute is changing nearly linearly, a value of n_pre = 4 works almost as well as a value of 2. Therefore, the value of n_pre = 4 has been adopted, however, a larger number of comparisons between observed and forecast contours should be made to confirm this conclusion.

Increasing the number of the Fourier components used to forecast the contours increases the computational time. To minimize the forecasting time,

choosing an optimal number of the Fourier components is critical. From Figures 8a and 8b it can be seen that Fourier component 1 has the largest amplitude among the components, and the amplitude of wave numbers larger than ten is negligible compared to the first one. Based on tests performed on the limited case study data set available for the development effort, it was found that inclusion of higher numbered Fourier components introduce only a small variation in the boundary shape and area covered by the contour. Based only on these criteria, the optimal number of Fourier components to produce a forecast is one. However, a forecast based on wave number one alone basically generates a forecast contour with a nearly round shape (without scaling by the aspect ratio), and the detail of the shape of the contours is missing. Since the shape of the cloud is sometimes important in determining special weather phenomena, a higher number of Fourier components should be used.

## 5. CONCLUSION

The RAPID system makes use of linear models to perform short term nowcasts of cloud contours and precipitation patterns derived from satellite imagery and radar data. The technique employs pure mathematical extrapolation, no meteorological or climatological information is required. Although only satellite infrared and radar reflectivity data are likely to be forecast with these techniques, the possibility of viewing and editing radar velocity and satellite visible data provide additional elements to the meteorologist contributing to his/her understanding of the current situation of the atmosphere.

APPENDIX A. USERS GUIDE FOR RAPID AND THE SEGMENTATION FORECAST METHOD

RAPID must be run on a VAX workstation with an 8-bit color monitor. It is currently being modified to run on a workstation operating with DECWINDOWS.

To run RAPID, execute the following two commands:

1) RAPID: == run user$disk_15:[alberto.rapid]main
2) RAPID

Upon execution of the main program the user is presented with a main menu. The main menu prompts the user for the type of data to be processed. The options are the following:

> Satellite Visible
> Satellite Infra-Red
> Radar Reflectivity
> Radar Velocity
> Exit

Once the data type is selected (the selection is done by highlighting the option on the menu through the use of the mouse), the user is presented with a second menu whose options are

> Extract & Forecast
> Extract ONLY
> Forecast ONLY
> Previous Menu
> Exit

Once in RAPID, the user has the option of processing the data through the EDITING module, the EXTRACT module and the FORECAST module or to go directly to the FORECAST module using pre-archived data that were previously processed.

The first option (Extract & Forecast) will guide the user through the INGEST module, the EDITING module, the EXTRACT module, on to the FORECAST module with a minimum of input from the user. The user is prompted for three input files because only three images at a time can be tracked by the system. The data file selected by the user is displayed on the workstation

with the EDITING module menu by its side. After editing and choosing the "Return to Main" option from the EDITING module menu, the data will be automatically contoured and placed in chain code files named OUT1.DAT, OUT2.DAT, and OUT3.DAT (EXTRACT module). All the data files that are created by the user are stored in the user's current directory. Then, the three images will be automatically retrieved from the chain code files, reconstructed and displayed (FORECAST module).

The FORECAST module menu has the following options:

> Track
> Forecast
> Evaluate
> Previous Menu
> Exit

Upon selection of the Track option of the FORECAST menu, a file will be opened to store the tracked contours. The file is automatically called TRACK.DAT. This file is to be used by the Whole Contour forecast technique. Through the mouse, the user then selects three contours to be tracked and forecast.

Selection of the Forecast option from the FORECAST menu will cause the forecasted contour to be displayed on the workstation screen. It is possible to forecast a whole image by selecting first the contours of lower threshold and then moving up to higher thresholds.

The Evaluate option of the FORECAST module menu provides a regression and correlation analysis of the three contours that have been selected by the user for tracking. Since the forecast techniques predict both the shape development and movement of the contours, a statistical analysis is performed on the centroids (used to predict movement) and the contour features (used to predict shape). Parameters of interest are presented to the user in tabular form for easy viewing. The following are some of the parameters used:

mean of dependent variable
variance of dependent variable
standard deviation of dependent variable
correlation coefficient
standard error of slope
standard error of intercept
SS regression
SS error
R-squared
R-squared (adjusted)
t-statistic

The independent variable is the time of the observation, while the dependent variable is the segment length. However, user discretion should be exercised in application of the Evaluate option since the 3 element timeseries supported by the current implementation of the technique is probably not long enough to provide meaningful statistics. This option is potentially valuable if the length of the timeseries is increased in the future.

The second option from the second menu (Extract ONLY) takes the user through the INGEST, EDITING, and EXTRACT modules. In this case, the user must input the name of the files where to store the images in chain code representation.

The third option from the second menu (Forecast Only) will make use of pre-processed data (data that has been contoured and archived) to reconstruct three images from which the user will select the contours to be tracked and forecast. The user enters the names of three data files containing images in chain code representation. The images are then reconstructed and displayed. When selecting the option Track, the user is prompted for the name of the file where the tracked contours must be stored. As the user selects a contour to be tracked, the outline of the contour will appear on the fourth quadrant of the window that was opened for display purposes.

## APPENDIX B. USERS GUIDE FOR THE WHOLE CONTOUR PROGRAM

The program is designed to be run in the VAX workstation environment with GKS, the NCAR graphics package and the IMSL routines. The program implementing the Whole Contour technique allows the user to select different data files which contain the contours extracted from the satellite or radar image. Since the RAPID system only allows three extracted contours in a data file, an additional program has to be run in order to combine more data files into one unique data file which contains a time sequence of the contour. All the data files which are used to run the Whole Contour program have been processed by running the program ADD.EXE. Figure B.1 gives a sample session of a run of ADD.EXE.

A flow diagram of the Whole Contour Forcast program is given in Figure B.2. The main program allows users to define the values of different parameters to perform the forecast. These parameter are:

> n_freq: the number of the Fourier components to be used to construct the forecast contours,
>
> n_order: the order of the prediction equation (Eq. 4.1)
>
> method: the method code which use the different sets of the forecast attributes (Table 4).

The parameter n_obs is the number of observations in the input data file and is set in ADD.EXE.

The range of the options (at present setting) are:

$1 \le$ n_obs $\le 20$
$2 \le$ n_pre $<$ obs
$1 \le$ n_freq $\le 20$
$1 \le$ n_order $<$n_pre
$1 \le$ method $\le 4$

However, the upper bound can be easily changed in the source code.

(1) set def arcdev$dua0:[users.amps.rapid.data]
(2) type <RUN ADD>, the following will appear sequentially on the screen, then answer the question:

```
Enter how many files will be used : 2
Enter name of file which stored the contours data : case19a.dat
Enter name of file which stored the contours data : case19b.dat
threshold =        83
threshold =        83
threshold =        83
threshold =        83
threshold =        83
threshold =        86
The access of the output file will be sequential, and
without recl and recordtype
What is the output file name : case19.dat

there are  6 contours ready for output.

Do you want all of them [N] : <CR>
```

If you want all the contours, type <Y or y>, the program will write the contours to the specified output file. Otherwise, press <return> and answer the following question:

```
The fisrt contour number you want to save : 1
The last  contour number you want to save : 5
```

Figure B.1 Sample session of the program ADD.EXE.

```
|------------------> Ask for the name of the file
|                    containing the contours
|
|                    Read the file and load the
|                    data into memory.  These are
|                    the observations
|                    sub: get_contours
|
|   |--------------> Get operational parameters:
|   |                sub: main_menu
|   |
|   |                Compute a feature vector
|   |                for each observation
|   |                sub: define_features
|   |
|   |                Predict feature vectors
|   |                These are the forecasts
|   |
|   |                Reconstruct the forecast
|   |                contours from the predicted
|   |                feature vectors
|   |
|   |    |---------> Ask for options
|   |    |           1: Display contours
|   |    |           2: Display features
|   |    |           3: New analysis with same data set
|   |    |           4: New analysis with new  data set
|   |    |           5: Exit
|   |    |
|   |    |           if option 1 is selected
|   |    |           display the user specificed contours
|   |    |-----------then go back for new options
|   |    |
|   |    |           if option 2 is selected
|   |    |           display the features
|   |    |-----------then go back for new options
|   |
|   |                if option 3 is selected
|   |                go back for a new set of
|   |--------------- operational parameters
|
|                    if option 4 is selected
|------------------- go back for a new data name and
                     a new set of operational parameters

                     if option 5 is selected
                     terminate the program
```

Figure B.2  A flow diagram of the whole contour forecast program.

Here is an example of how the program should be run:

(i) set default to user$disk_15:[huang.cloud]

(ii) type <RUN PREDICTION>

The following will appear on the screen (<CR> means to press the return key after the input):

```
>    Does the output go to laser printer [N] : <CR>
>    file name containing the contours: case12.dat <CR>
>    there are    12 observations. (n_obs)
>    enter: the number of observations to base prediction on (n_pre): 4<CR>
>    enter: the number of Fourier components (n_freq): 5 <CR>
>    enter: the order of the prediction model (n_order): 1 <CR>
>    enter: the method code: 2 <CR>
```

At this time the program will compute the forecast. After the calculation is completed, the following menu will appear:

```
>    options:
>
>    1: Display contours
>    2: Display features
>    3: New analysis with same data set
>    4: New analysis with new data set
>    5: Advance Frame
>    6: Exit
>
>    selection:
>
```

This is the main menu. Choose the number corresponding to your selection.

If you chose option one, the following will appear:

```
>    enter observation numbers : 1,2,3,4,5,6 <CR>
>    enter the degree of smoothness : 20 <CR>
>    enter forecast numbers : 5,6 <CR>
>    use absolute coordinate [N] : y <CR> >
```

The plot of the contours will appear on the upper left corner of the screen. If option 1 is chosen repeatedly, the plot will appear on the second, third or fourth frame. If all the frames have been used up, the next plots will go to frame one, frame two, etc.

If you chose option 2 on the main menu, the first four features of the contours will be displayed on the screen. To see the other features press <CR>.

If you chose option 3 on the main menu, you will be prompted for the new input parameter values to be used for the new forecast.

If you chose option 4 on the main menu, you will be prompted for the new input data file name and the new input parameter values to be used for the new forecast.

If you chose option 5 on the main menu, the frames of the contour plot on the screen will be sent to a data file, which will be printed, and the new frames will appear on the screen.

Choose option 6 if you want to stop the program.

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